Precipitation and Temperature Characteristics of Forested Watersheds in Central Arizona

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Abstract

Precipitation and temperature characteristics of the Utah and alligator juniper woodlands and ponderosa pine forest types, on the Beaver Creek experimental watersheds, are described using 23 years of record. Mean annual precipitation ranges from 17.6 inches in the Utah juniper type at 5,000 feet elevation to 25.0 inches in the ponderosa pine type at 7,400 feet elevation. Average precipitation is greater for winter storms than for summer storms. Precipitation intensity exceeding 3 inches per hour for 30 minutes' duration may be expected to occur on the average at 25-year intervals on all three vegetation types. Temperatures are closely correlated with elevation. The climatic patterns, both precipitation and temperature, are quite representative of similar vegetation types and fit into a continuum within Arizona and New Mexico.

[1]*Headquarters is in Fort Collins, in cooperation with Colorado State University. Research reported here was conducted at the Station's Research Work Unit at Flagstaff, in cooperation with Northern Arizona University.*

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INTRODUCTION

Ponderosa pine (*Pinus ponderosa* Laws.) forests and the Utah juniper (*Juniperus osteosperma* Little) and alligator juniper (*J. deppeana* Steud.) woodlands in north-central Arizona have been intensively studied by the USDA Forest Service as part of the Beaver Creek watershed network (Brown 1965, 1970, 1971; Brown et al. 1970, 1974; Clary et al. 1974; Williams and Anderson 1967). Climatic data such as precipitation, temperature, and humidity have been collected for more than 20 years, primarily to determine the influence of local climate on water runoff from forested watersheds. In addition, long-term climatic data are important to managers for reasons such as estimating biomass production and sediment yield, and for road planning. This paper characterizes the precipitation and temperature regimes of the three vegetation types within the Beaver Creek watersheds, compares these regimes with other areas of the Southwest, and projects probabilities of future storm intensities.

The hypothesis tested is that precipitation regimes on the Beaver Creek watersheds represent substantial areas of similar vegetation types in Arizona and New Mexico. Further, the temperature regime on the Beaver Creek watersheds is within a continuum of the greater temperature regime in Arizona.

SITE DESCRIPTION

The Beaver Creek experimental watersheds, which drain into the Verde River, are in the Mogollon Plateau region of Arizona, about 25 to 35 miles south of Flagstaff (fig. 1). Bedrock under the watershed is basalt with some minor faulting (Beus et al. 1966, Scholtz 1968). The watersheds are characterized by breaks, steep canyons, and valleys. Average elevations of the Utah juniper watersheds range from 5,200 to 5,500 feet, the alligator juniper watersheds range from 6,200 to 6,400 feet, and those in ponderosa pine range from 6,400 to 8,000 feet. The Beaver Creek watershed as a whole slopes about 3% to the southwest.

The predominant soil of the juniper watersheds is a Udic Chromustert, Springerville series (surface texture-clay), developed in material weathered from basalt. Predominant soils of the pine watersheds are Eutroboralfs and Argiborolls of Brollier (loam to fine clay), Siesta (silt loam), and Sponseller series (stony silt loam), and are developed on basalt and cinders (Williams and Anderson 1967).

The position of the Mogollon Rim in relation to the central valleys and the desert to the southwest strongly influences the temperature regime and precipitation patterns. According to the Koppen classification scheme discussed by Trewartha (1968), the area is classified as temperate, continental: mean monthly temperature is above 50° F during 4 to 7 months of the year, and precipitation occurs every season of the year, with rain in summer and snow in winter. Moisture for the moderately heavy precipitation of July and August comes almost entirely from the Gulf of Mexico. However, most of the high-record summer rains are associated with deep surges of tropical air from the Gulf of California and the Pacific Ocean. Most winter precipitation is the result of frontal storms moving east or northeast from the Pacific Ocean. Late spring (May-June) and early fall (September-November) are generally dry periods (Sellers and Hill 1974).

METHODS

Instrumentation

Precipitation, temperature, and humidity gages were installed to monitor watershed climate beginning in 1957. Gages were added to the climatic monitoring network when the study area was expanded in 1962, 1965, 1972, and 1976. After watershed evaluation studies were completed, some gages were removed from the network in 1965, 1973, and 1976. The network now consists of 44 gages (fig. 2). Length of record of existing gages ranges from 4 to 23 years.

Recording gages for precipitation are of the weighing type and produce ink trace records on 24-hour charts. Standard (nonrecording) gages are read by weighing every 2 weeks; they are charged with mineral oil to prevent evaporation, and additionally with ethylene glycol during winter to prevent freezing. The 8-inch-diameter rims are 2 m above ground.

Hygrothermographs in weather instrument shelters are used to continuously record both temperature and humidity at seven locations. Humidity gages are calibrated periodically using an Assman psychrometer as a standard. The temperature gages are calibrated with maximum, minimum, and standard thermometers. Five weather stations are on pine watersheds, and one each is on Utah juniper and alligator juniper watersheds.

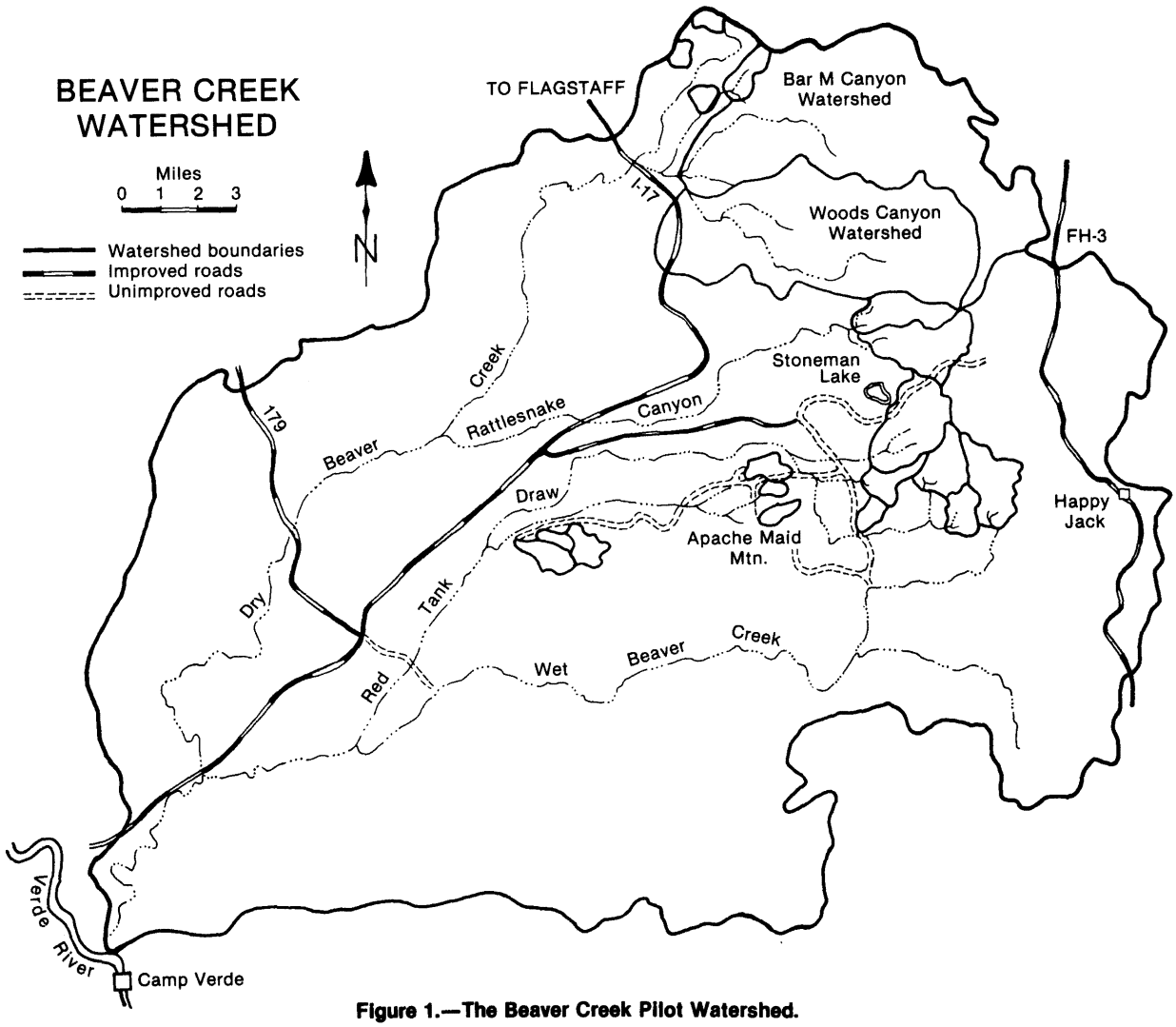

Figure 1.—The Beaver Creek Pilot Watershed.

Climatic Data Processing

Climatic records are kept on a water year basis which begins on October 1 of the previous calendar year. Winter season is defined as the months October through April; summer, May through September.

Precipitation data gathered from recording and standard gages are processed through a group of computer programs each water year. The following information is generated by these programs:

- amount and type of precipitation (rain, snow, or mixed).
- duration (in hours) of storms at each gage.
- maximum n-minute rain intensities per storm for six values of n (5, 15, 30, 60, 120, 360) at each gage. Storm intensities are calculated only for rain events with precipitation greater than 0.25 inches.
- amount and duration of storms by watershed.
- summaries of precipitation by day, month, season, and year for each gage and watershed.

Information from the 24-hour precipitation charts is used to calculate the storm intensity and duration data. Volume data from the standard gages represent the absolute precipitation amount. Average precipitation on a watershed is found by combining the records of gages representing portions of the watershed according to Thiessen formulas (Thiessen 1911). Daily maximum and minimum temperature and humidity values are read from the continuous trace charts and are stored in computer data files. Climatic data are available for reference from Rocky Mountain Forest and Range Experiment Station, Flagstaff.

DATA ANALYSIS

Records from one precipitation gage each in the Utah and alligator juniper types were used in calculating the long-term annual precipitation averages, while records from seven gages, each within a different experimental watershed, were used for ponderosa pine. Each of the gages selected represents 23 continuous years of record. The gage in the Utah juniper represented a 1,000-acre watershed area ranging in elevation from 5,000 to 5,400 feet, the gage in the alligator juniper

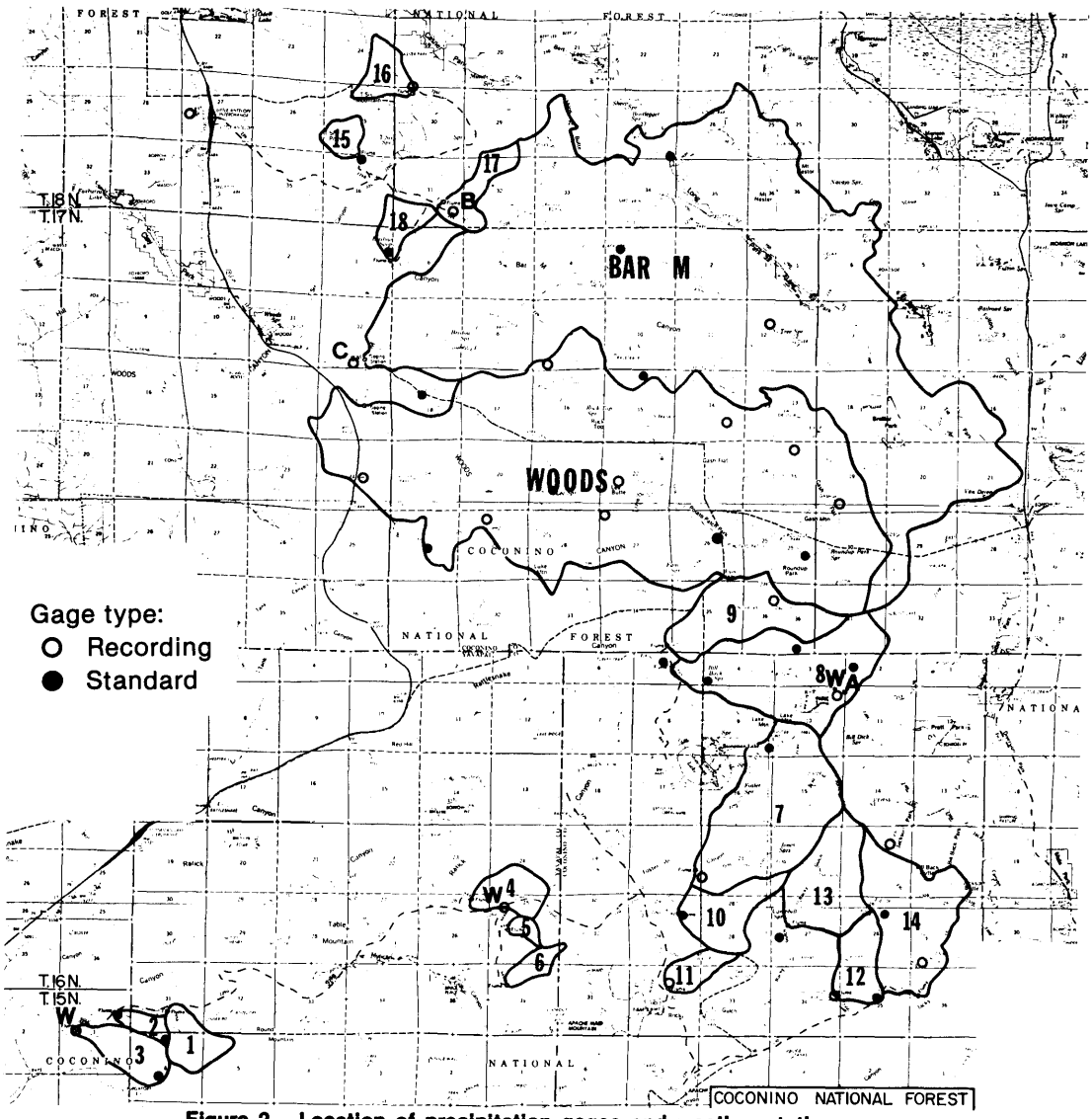

Figure 2.—Location of precipitation gages and weather stations on the Beaver Creek watershed, Arizona. (W = weather station; A, B, and C = gages used in correlation analysis.)

represented a 600-acre watershed area with an elevational range of 6,300 to 6,400 feet. The seven pine gages represent about 6,000 acres of watershed area ranging in elevation from 6,400 to 7,500 feet.

Some stations are operational in the summer only, and the long-term monthly precipitation averages for the pine were calculated using three gages in addition to the seven used for the annual precipitation. These three gages had a continuous record in the months they represented for the entire 23-year period. When more than one gage was used to represent a vegetation type in a given month and year, volumes of these gages were averaged. The reported standard errors indicate the variation of these averaged volumes.

An estimate of the spatial variation among precipitation gages in the pine type was found by calculating seasonal and annual averages for 28 to 30 gages for five separate years. These years represent low, medium, and high amounts of annual precipitation. Variability of precipitation among gages was uniformly low; coefficients of variation ranged from 8% to 19% and were generally about 12%.

One station in each of the three vegetation types was used to characterize the temperature, humidity, and storm regimes (fig. 2). Station 1 and 9 represent the Utah juniper and alligator juniper types respectively. They are the only stations in these types at which temperature and humidity records are kept. Station 20 was chosen to represent the pine type because it has the longest continuous record of temperature and humidity in the pine watersheds. The elevations of these gages are: Utah juniper—5,000 feet, alligator juniper—6,240 feet, and ponderosa pine—7,400 feet. Records from the years 1958-1980 were used to calculate long-term averages of temperature and storm parameters.

One of the desired applications of historical precipitation data is to predict the probable frequency of rainfall intensity for future events. Summer rainfall data were used to predict the expected frequency (recur-

rence interval) of maximum intensities for durations ranging from 5 to 360 minutes.

First, the annual maximum intensities for each time interval (5, 15, 30, 60, 120 and 360 minutes) for the 23 years of record were listed in descending order.

Second, recurrence intervals (T) were paired with these ranked intensities (Chow 1964) where T = (n + 1)/m; n = the number of years of record (here 23), and m = order number of the intensities. This produced a series ranging from 24 to 1.043.

Next, the T values were transformed to K values in order to establish a linear relationship between intensity and recurrence interval (Chow 1953):

$$K = (-\sqrt{6}/\pi)\left\{\gamma + \ln\ln[T/(T-1)]\right\}$$

where γ, a Euler's constant = 0.57721.

Linear regression coefficients were then derived for each time duration and each of three precipitation stations. The differences of regression slopes among vegetation types were tested for each time interval using covariance analysis.

Only summer storms were considered in the analysis. High intensity summer rainfall has direct bearing on flood events, whereas winter storms rarely exceed intensities of 1 inch per hour.

The relationship between precipitation and elevation was analyzed using linear regression. Eleven-year annual and seasonal averages of 16 gages ranging in elevation from 5,000 to 7,600 feet were used for the analysis. To include more gages, the 11-year period (1963 to 1973) instead of the 23-year period (1958 to 1980) was chosen.

Beaver Creek climate in relation to Arizona as a whole was examined in terms of average annual precipitation with respect to elevation at 77 stations. Data were from National Climatic Center (1980).

Variability among temperature stations in the pine type was estimated by averaging the monthly maximum and minimum temperatures of five stations for two separate years. The coefficients of variation are generally low (about 7%) and range from 3% to 20%. Maximum temperatures (CV ≅ 5%) were less variable than the minimum temperatures (CV ≅ 10%). There is no estimate of the spatial variability of temperature on the juniper watersheds.

RESULTS AND DISCUSSION

Precipitation

Annual and Seasonal Precipitation

Mean annual precipitation is 17.4 inches in Utah juniper, 21.8 inches in alligator juniper, and 25.0 inches in ponderosa pine (table 1). Annual precipitation extremes in the period of record were 7.6 and 26.0 inches in Utah juniper, 12.6 and 34.1 inches in alligator juniper, and 15.2 and 39.4 inches in ponderosa pine. These record lows and highs were set in two consecutive years; the wettest year was 1973, followed by the driest year in 1974.

Annual precipitation for the three vegetation types on the Beaver Creek watersheds is similar to other sites in Arizona with comparable orographic relationships. New Mexico sites are somewhat similar; however, they differ slightly in that the winters are dryer. A higher proportion of precipitation occurs in July and August in New Mexico than in Arizona. Since precipi-

Table 1.—Annual precipitation (inches) on Utah and alligator juniper woodland and ponderosa pine forests, Beaver Creek watersheds, Arizona

	Utah juniper			Alligator juniper			Pine		
Year	Winter	Summer	Total	Winter	Summer	Total	Winter	Summer	Total
1958	12.28	8.73	21.01	16.56	10.35	26.91	13.76	11.93	25.69
1959	6.12	6.33	12.45	6.73	6.45	13.18	8.69	8.31	16.99
1960	11.81	5.91	17.72	15.25	7.36	22.61	18.33	6.29	24.62
1961	8.49	8.85	17.34	10.57	10.54	21.11	12.67	11.40	24.07
1962	9.97	4.63	14.60	13.13	5.38	18.51	17.42	6.03	23.45
1963	6.44	6.16	12.60	8.50	7.23	15.73	10.82	8.49	19.29
1964	8.70	9.33	18.03	10.23	6.42	16.65	13.69	7.37	21.06
1965	15.97	7.01	22.98	19.19	8.56	27.75	22.98	10.19	33.17
1966	13.09	5.38	18.47	16.81	7.58	24.39	18.87	7.92	26.79
1967	7.47	9.68	17.15	10.40	7.69	18.09	12.48	12.31	24.79
1968	11.16	3.55	14.71	13.33	6.87	20.20	17.08	6.81	23.90
1969	11.67	6.95	18.62	15.94	6.58	22.52	19.31	6.43	25.73
1970	9.57	8.08	17.65	11.84	10.33	22.17	12.56	11.05	23.61
1971	5.55	7.71	13.26	6.99	9.45	16.44	8.75	10.70	19.45
1972	6.20	6.16	12.36	8.46	8.44	16.90	10.13	9.19	19.32
1973	23.83	2.20	26.03	30.38	3.76	34.14	35.68	3.70	39.38
1974	5.59	1.97	7.56	7.95	4.62	12.57	9.95	5.19	15.15
1975	11.07	3.28	14.35	13.91	4.84	18.75	16.72	5.32	22.04
1976	10.17	8.00	18.17	13.61	7.66	21.27	16.28	9.65	25.93
1977	6.42	7.43	13.85	7.26	12.85	20.11	8.93	11.45	20.38
1978	18.54	2.56	21.10	23.35	3.76	27.11	24.92	4.43	29.35
1979	19.80	4.18	23.98	25.30	5.02	30.32	28.06	6.12	34.18
1980	20.33	4.96	25.29	27.17	6.56	33.73	29.92	5.50	35.43
Mean	11.31	6.05	17.36	14.47	7.32	21.79	16.87	8.08	24.95
SE	1.08	.48	.96	1.40	.48	1.24	1.52	.55	1.26

tation increases as air masses rise and cool, and winds are predominantly southwesterly, in Arizona precipitation increases on southwestern slopes with increased elevation. Areas of equivalent elevation further east which receive less precipitation reflect the rain shadow effect.

The phenomenon of increasing precipitation with increasing elevation is typically exemplified in the annual precipitation on the Beaver Creek watersheds. The principle is also evident at Santa Rita, Sierra Ancha, and McNary, as well as several other locations in Arizona.

For equivalent elevations, precipitation is slightly less at Flagstaff and Fort Valley because they are further east and north of the elevation rise. Stations still further east and at slightly lower elevations receive considerably less precipitation. Examples are Wapatki, Leupp, and Winslow. Annual precipitation on pinyon juniper woodlands ranges from 8 to 25 inches in the Southwest (Tueller and Clark 1975) and from 11.8 to 19.7 inches in Arizona (Clary and Jameson 1981). Beschta (1976) reported a range of 15 to 35 inches of annual precipitation in the Arizona ponderosa pine type with most of the areas receiving 20 to 25 inches.

The year to year variation is too great to permit detection of precipitation cycles in the 23 years of data. However, if the data are examined as 5-year moving averages some trends appear (fig. 3). The data show an indication of a 12-year cycle. The greatest mean annual precipitation was received during the period 1976-1980, while the driest period was 1959-1963.

Seasonal distribution of precipitation varies little from type to type. Winter precipitation accounts for 65%, 66%, and 68% of the annual in the Utah juniper, alligator juniper, and ponderosa pine, respectively. The standard errors are greater for winter precipitation than for summer in all three vegetation types. However, variation in precipitation between-years (reflected in the standard errors) increased with elevation from Utah juniper to ponderosa pine in both winter and summer (table 1). The Utah juniper watershed receives about 30% less annual precipitation than the ponderosa pine watersheds; alligator juniper receives about 13% less. These differences increase during the winter season and subside during the summer.

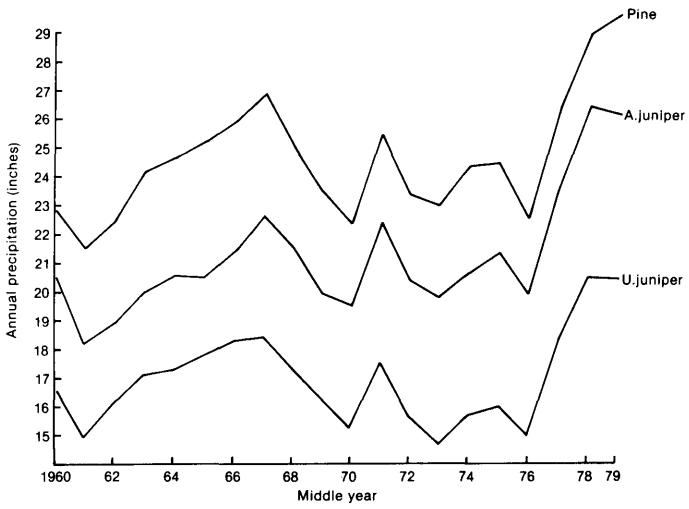

Figure 3.—Five-year moving average annual precipitation, Beaver Creek watersheds (Stations 1, 9, 20).

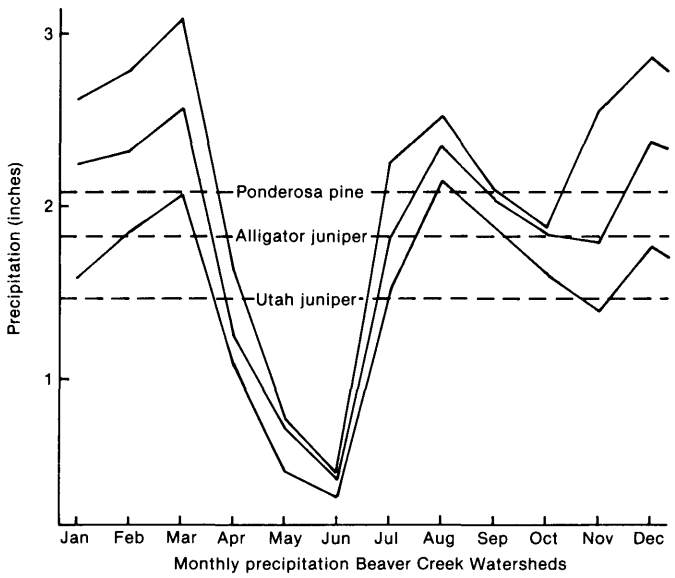

Figure 4.—Annual average of mean monthly precipitation (inches) on Utah and alligator juniper and ponderosa pine stations, Beaver Creek watersheds, Arizona 1958-1980. The horizontal dashed lines indicate averages of the twelve monthly values.

Monthly Precipitation

A distinct period of low precipitation occurs on the Beaver Creek watersheds in May and June (fig. 4). June mean rainfall was 0.32, 0.42, and 0.46 inches on Utah juniper, alligator juniper, and ponderosa pine gages, respectively. Seasonal precipitation patterns also show two distinct winter peaks. For ponderosa pine and alligator juniper, the highest peak occurs in March when mean precipitation is 3.08 inches in ponderosa pine and 2.56 inches in alligator juniper. A summer monsoon peak typically occurs in August. The Utah juniper type receives more precipitation in August than in either March or December. However, the differences among watersheds were greater during the winter months than in summer. Sellers and Hill (1974) indicate that cool season precipitation is more variable from year to year than warm season precipitation. Beaver Creek data support this conclusion.

The pattern of monthly precipitation on the Beaver Creek watersheds agrees with that reported by Beschta (1976) for the ponderosa pine type in central Arizona. Pinyon-juniper sites in Colorado, Utah, and Arizona also have a similar monthly precipitation pattern (West et al. 1975). However, Springfield (1976) found that pinyon-juniper areas in eastern New Mexico receive 75% of the yearly precipitation during the growing season (April to September); Beaver Creek juniper sites receive only 40% of the yearly precipitation during the same period.

The pattern that Springfield described coincides with the pattern which generally prevails in New Mexico, with maximum precipitation in July and August, tapering off to a minimum in January. The monthly march of precipitation on the Beaver Creek watersheds follows the general pattern of the larger plateau region of Arizona (Sellers and Hill 1974) except that the proportion of precipitation received during the summer is greater in the general area than on Beaver Creek. The higher peak of winter precipitation in the ponderosa type is reflected in storage of snow. The lower summer peak coincides with lack of summer runoff from the watersheds.

Summer precipitation patterns presented by Sellers and Hill (1974) is exemplified in the Fort Valley record (not shown); more rainfall is received at Fort Valley in July than at the Beaver Creek pine stations. Since ponderosa pine responds to July precipitation in growth (Minor, personal communication)[2] ponderosa pine would be expected to be larger in a given age class at Fort Valley than on the Beaver Creek watersheds.

Storm Variability

To assess the variability of certain storm parameters for the ponderosa pine type, values for 20 gages were averaged for water year 1977 (tables 2 and 3). The variability for these parameters is higher than that found for average precipitation or temperature. This is likely a result of the variability of individual storms together with the partitioning of storm parameters into storm volume classes. There is no estimate of the spatial variability of storm parameters for the juniper watersheds.

Number of Storms

The total number of storms increases with elevation (table 4). Utah juniper receives 55 storms per year, alligator juniper receives 59, while 68 storms per year occur on the ponderosa pine watersheds. More than half the storms are 0.25 inch or less. Fewer than 8% of summer storms exceed 0.75 inch. In contrast, 8%, 11%, and 19% of winter storms exceed 1 inch in the Utah juniper, alligator juniper, and pine types, respectively.

[2]*Charles O. Minor, Professor of Forestry, Northern Arizona University, Flagstaff.*

Table 3.—Average storm intensity (inches/hr) of 20 gages for summer storms in the ponderosa pine type for water year 1977, Beaver Creek watersheds, Arizona

Storm class (inches)		Time interval					
		5	15	30	60	120	360
0.26-0.50	Mean	0.93	0.57	0.37	0.22	0.12	0.11
	SE	0.59	0.03	0.02	0.01	0.01	0.01
0.51-0.75	Mean	1.26	0.77	0.49	0.29	0.12	0.04
	SE	0.19	0.11	0.07	0.04	0.02	0.01
0.76-1.00	Mean	0.98	0.69	0.47	0.28	0.13	0.05
	SE	0.23	0.15	0.10	0.05	0.03	0.01
>1.00	Mean	1.18	0.88	0.67	0.48	0.29	0.15
	SE	0.18	0.13	0.08	0.05	0.02	0.01

Storm Size

Considerably more winter precipitation occurs in the ponderosa pine type, in storms exceeding 1 inch, than in the juniper type (table 5). The amounts are 4.2 inches, 6.5 inches, and 12.6 inches in the Utah juniper, alligator juniper, and ponderosa pine. These amounts are 37%, 45%, and 62% of the winter season precipitation. The above contrasts are much less for summer storms. About 21% of summer rainfall occurs in storms over 1 inch in all three types. A high proportion of summer precipitation occurs in the <0.25 inch size class in all three types. The average size of storm within each storm size class is the same for all classes under 1 inch (table 6), but the average amount in the >1.0 class is greater in the pine than in the juniper type.

Storm Duration

Duration of storms by size class and by season in the three vegetation types are shown in table 7. Winter storms last approximately three times longer than summer storms in all size classes and in all three vegetation types. Storm duration within a size class is very similar among the three vegetation types. Since summer storms are considerably shorter within a storm size class, it is evident that their intensity is considerably greater.

Table 2.—Average storm duration and number of storms for 20 gages in the ponderosa pine type for water year 1977, Beaver Creek watersheds, Arizona

Storm class (inches)	Winter				Summer			
	Average duration (hr)	SE	Average number of storms	SE	Average duration (hr)	SE	Average number of storms	SE
0.02-0.25	2.58	0.11	17.4	0.4	1.85	0.08	29.3	1.0
0.26-0.50	9.97	0.80	4.3	0.3	4.06	0.29	7.4	0.6
0.51-0.75	12.30	1.52	2.2	0.2	4.01	0.72	2.2	0.3
0.76-1.00	13.04	1.63	1.1	0.2	15.39	2.54	1.5	0.3
>1.00	27.03	0.85	3.1	0.2	12.45	0.87	1.7	0.1

Table 4.—Average number of storms per season by size class in Utah juniper and alligator juniper woodland and ponderosa pine forest, Beaver Creek watersheds, Arizona

Storm class (inches)		Utah juniper		Alligator juniper		Ponderosa pine	
		Winter	Summer	Winter	Summer	Winter	Summer
0.02-0.25	Mean	18.00	16.96	16.74	18.09	16.83	24.04
	SE	1.50	0.72	1.15	0.94	1.28	0.89
0.26-0.50	Mean	5.91	4.39	6.43	4.57	5.52	6.13
	SE	0.56	0.52	0.73	0.36	0.50	0.55
0.51-0.75	Mean	2.48	1.78	3.09	2.44	3.39	1.65
	SE	0.33	0.33	0.44	0.27	0.41	0.27
0.76-1.00	Mean	1.83	0.78	2.30	0.96	2.22	1.17
	SE	0.26	0.20	0.30	0.21	0.34	0.21
> 1.00	Mean	2.48	0.78	3.39	0.96	6.52	1.04
	SE	0.36	0.18	0.47	0.18	0.67	0.22

Table 5.—Average total precipitation (inches) per season in each storm size class. Twenty-three years of record in Utah juniper, alligator juniper, and ponderosa pine vegetation types, Beaver Creek watersheds, Arizona

Storm class (inches)	Utah juniper		Alligator juniper		Ponderosa pine	
	Winter	Summer	Winter	Summer	Winter	Summer
0.02-0.25	1.80	1.36	1.67	1.81	1.68	2.40
0.26-0.50	2.19	1.58	2.38	1.65	1.99	2.21
0.51-0.75	1.56	1.07	1.92	1.51	2.10	0.99
0.76-1.00	1.57	0.68	1.98	0.84	1.93	1.02
> 1.00	4.19	1.27	6.51	1.52	12.65	1.75

Table 6.—Average size of individual storm (inches) subdivided by storm size class and season for Utah juniper, alligator juniper and ponderosa pine types, Beaver Creek watersheds, Arizona 1958 to 1980

Storm class (inches)		Utah juniper		Alligator juniper		Ponderosa pine	
		Winter	Summer	Winter	Summer	Winter	Summer
0.02-0.25	Mean	0.10	0.08	0.10	0.10	0.10	0.10
	SE	.003	.003	.003	.003	.003	.003
0.26-0.50	Mean	.37	.36.	37	.36	.36	.36
	SE	.006	.008	.006	.007	.006	.006
0.51-0.75	Mean	.63	.60	.62	.62	.62	.60
	SE	.010	.011	.008	.010	.008	.011
0.76-1.00	Mean	.86	.87	.86	.87	.87	.87
	SE	.012	.015	.010	.016	.011	.010
> 1.00	Mean	1.69	1.63	1.92	.1.58	1.94	1.68
	SE	.084	.173	.116	.165	.086	.237

Table 7.—Average storm duration (hours) by size class and season in Utah juniper and alligator juniper woodlands and ponderosa pine forest, Beaver Creek watersheds, Arizona 1958-1980

Storm class (inches)		Utah juniper		Alligator juniper		Ponderosa pine	
		Winter	Summer	Winter	Summer	Winter	Summer
0.02-0.25	Mean	2.99	1.50	2.99	1.39	3.11	1.54
	SE	0.17	0.10	1.17	0.08	0.16	0.09
0.26-0.50	Mean	8.79	3.69	9.78	4.33	9.27	4.11
	SE	0.42	0.34	0.54	0.40	0.46	0.30
0.51-0.75	Mean	15.00	4.54	14.21	5.33	14.67	8.28
	SE	0.89	0.67	0.82	0.62	0.92	1.06
0.76-1.00	Mean	19.36	8.63	20.53	5.74	17.16	8.49
	SE	1.25	1.49	1.16	1.28	1.08	1.51
> 1.00	Mean	29.54	7.35	30.16	8.68	30.58	11.17
	SE	2.16	1.34	2.01	1.59	1.28	2.06

Storm Intensity Classification

Storms can be classified or grouped based on intensities for selected n-minute durations. The number of occurrences of intensity rates of storms occurring in the three vegetation types is presented in table 8. Only summer rainfall events are considered, since winter rainfall and snow events have uniformly low intensities (generally less than 0.5 inch per hour).

Intensity-Duration-Frequency Characteristics

The curves in figures 5, 6, and 7 are for recurrence intervals of 2 to 50 years and summer storm durations of 5 to 360 minutes. Curves are linear regression of maximum annual intensities on a transformation of recurrence intervals. The r^2 values ranged from 0.870 to 0.993 (table 9). Return period intensity values for 24 years and longer were determined by linear interpolation. As such, these must be used with caution. Note that the recurrence interval is the average interval during which an intensity of a given duration will recur as an annual seasonal maximum.

The differences of regression slopes among vegetation types were tested for each line interval using covariance analysis. The intensity for 5 minutes' duration of a storm of 25 year recurrence was calculated to be 6.4 inches per hour at the pine station, 6.2 inches per hour at the alligator juniper station, and 4.3 inches per hour at the Utah juniper station. The projected intensities were neither consistent nor statistically significantly different among vegetation types for durations of 15 minutes or longer.

Using a similar analytical approach, Fletcher et al. (1981) found differences in regression slopes among zones in a Utah barometer watershed. However, much of their difference may be attributed to averaging different number of gages in each zone to calculate storm maximum intensities. In the 23 years of record, the greatest intensity for a duration of 15 minutes was 3.6 inches. Intensity of over 3 inches occurred on three occasions. No storm exceeded an intensity of 2.1 inches per hour for one hour duration and only one storm, in the alligator juniper, achieved an intensity of 3.2 inches per hour for 30 minutes' duration. At high intensities and long durations, the records are very similar in the three vegetation types.

The average intensity of summer rainstorms in each of the vegetation types are shown in table 10. Large storms (in terms of precipitation amount) have greater average intensities. Further, in the >1.0 inch size class in all time intervals, average intensities are of the order Utah juniper > alligator juniper > pine. In the 0.76 to 1.0 inch size class, in time intervals of 120 minutes or less, the intensities by vegetation type change to the order alligator juniper > pine > Utah juniper. In the 0.51 to 0.75 inch size class, in each time interval, intensities at Utah and alligator watersheds are about equal but greater than in the pine.

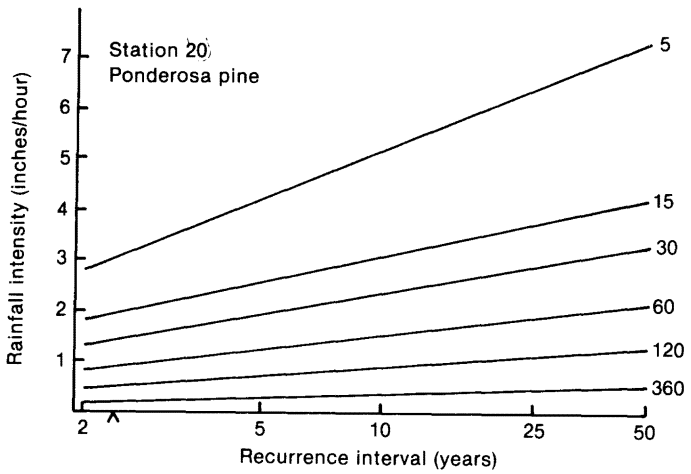

Figure 5.—Rainfall intensity-duration-frequency curves for ponderosa pine type, Beaver Creek watershed, Arizona. Based on 23 years of record.

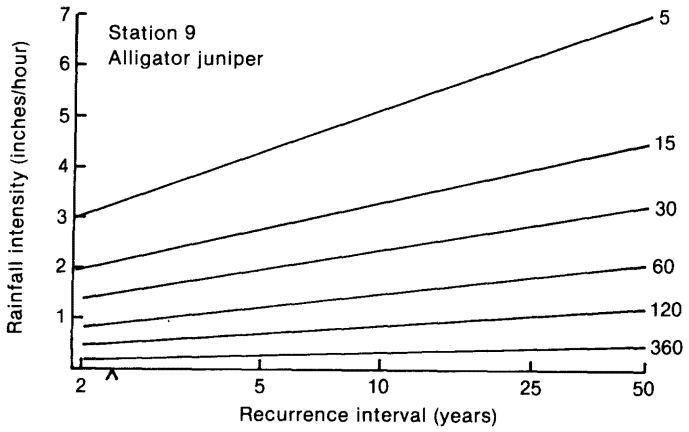

Figure 6.—Rainfall intensity-duration-frequency curves for alligator juniper type, Beaver Creek watershed, Arizona. Based on 23 years of record.

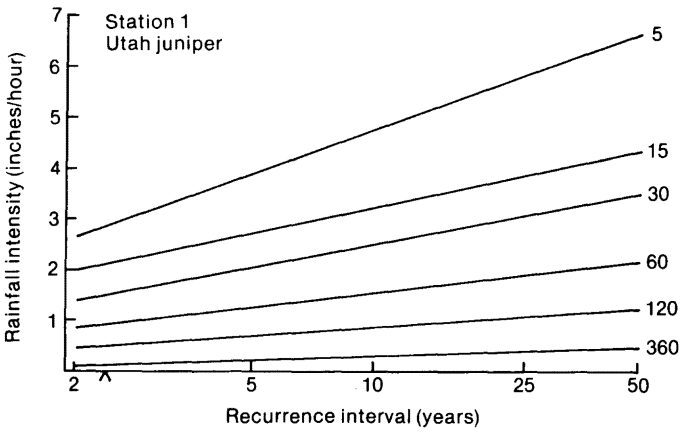

Figure 7.—Rainfall intensity-duration-frequency for Utah juniper type, Beaver Creek watershed, Arizona. Based on 23 years of record.

Table 8.—Storm intensity class frequencies for summer storms ≥ 0.25 inches. Summer season (May-September) for years 1958-1980. Three gages, one each on Utah juniper (U), alligator juniper (A), and ponderosa pine (P) vegetation type. Beaver Creek watersheds, Arizona 1958-1980

Duration (minutes)	Veg. type	Storm intensity class (inches per hour)							
		≤.5	.6-1.0	1.1-1.5	1.6-2.0	2.1-2.9	3.0-3.9	4.0-4.9	≥5.0
5	P	76	62	45	23	24	6	2	3
	A	53	42	32	35	31	13	6	2
	U	45	41	36	25	21	9	2	3
15	P	103	60	28	11	14	2	0	0
	A	72	59	66	26	14	3	0	0
	U	59	57	34	17	8	3	0	0
30	P	157	50	17	7	3	0	0	0
	A	105	67	24	5	3	1	0	0
	U	95	50	17	7	4	0	0	0
60	P	183	24	4	2	0	0		
	A	142	31	5	1	1	0		
	U	125	17	4	1	0	0		
120	P	172	5	1	0	0			
	A	136	8	1	0	0			
	U	111	6	1	0	0			
360	P	82	1	0					
	A	61	1	0					
	U	53	0	0					

Table 9.—Regression characteristics of annual maximum rainfall intensities for durations of 5 to 360 minutes at Utah juniper, alligator juniper, and ponderosa pine precipitation stations in relation to frequency factor K

Station	Duration	Intercept	Slope	r^2	SE
U. juniper	5	2.837	1.4698	0.9783	0.193
	15	2.085	0.8613	0.9630	0.149
	30	1.478	0.7881	0.9815	0.095
	60	0.912	0.4885	0.9760	0.068
	120	0.510	0.2711	0.9725	0.040
	360	0.192	0.1055	0.9583	0.019
A. juniper	5	3.273	1.4452	0.9931	0.107
	15	2.120	0.8309	0.9672	0.135
	30	1.507	0.6683	0.9517	0.133
	60	0.911	0.4518	0.9230	0.115
	120	0.511	0.2764	0.9103	0.077
	360	0.191	0.1169	0.8784	0.038
P. pine	5	3.038	1.6625	0.9627	0.289
	15	1.922	0.8866	0.9467	0.186
	30	1.396	0.7383	0.9656	0.123
	60	0.878	0.4935	0.9860	0.052
	120	0.509	0.2986	0.9377	0.068
	360	0.206	0.1321	0.8703	0.045

Correlations Among Gages

Summer storms are relatively small, and are erratic in their tracking patterns as compared to the broad frontal systems in winter. Because of this, amounts of precipitation received on a particular forest type are more nearly the same in winter than in the summer.

Three gages in the pine type, chosen for their wide spread location and length of record, illustrate this phenomenon. A correlation analysis was performed among the three gages using the yearly seasonal and annual precipitation for 18 consecutive years as the variables. The gages used (A, B, C) are indicated in figure 2.

Correlations among gages were all statistically significant at the 0.05 level. The correlation matrix is shown below:

Gage combination	R^2 values		
	Annual	Winter	Summer
A,B	0.91	0.96	0.61
A,C	0.92	0.95	0.64
B,C	0.98	0.99	0.73

Table 10.—Average intensity (inches/hour) of storms for four storm classes—summer only, Beaver Creek watersheds, Arizona 1958-1980

Time interval	Utah juniper Size class (inches)				Alligator juniper Size class (inches)				Ponderosa pine Size class (inches)			
(minutes)	.25-.50	.51-.75	.76-1.00	>1.00	.25-.50	.51-.75	.76-1.00	>1.00	.25-.50	.51-.75	.76-1.00	>1.00
5 Mean	0.98	1.59	1.60	2.64	1.01	1.74	2.26	2.26	0.87	1.23	2.05	1.76
SE	.077	.174	.230	.312	.074	.163	.264	.293	.053	.205	.297	.272
15 Mean	.64	1.08	1.19	2.05	.64	1.12	1.64	1.75	.59	.76	1.35	1.51
SE	.038	.088	.177	.211	.038	.084	.163	.209	.030	.090	.138	.238
30 Mean	.40	.70	.80	1.53	.40	.70	1.07	1.35	.39	.50	.94	1.14
SE	.021	.054	.117	.175	.021	.046	.096	.169	.018	.046	.095	.186
60 Mean	.22	.38	.45	.93	.22	.39	.63	.91	.22	.32	.54	.72
SE	.012	.027	.052	.111	.012	.022	.047	.108	.009	.024	.047	.120
120 Mean	.12	.21	.27	.54	.12	.21	.34	.51	.12	.19	.29	.44
SE	.007	.013	.022	.067	.006	.011	.023	.063	.005	.012	.021	.073
360 Mean	.05	.08	.11	.23	.05	.08	.13	.21	.05	.07	.10	.19
SE	.004	.005	.007	.027	.003	.005	.009	.043	.003	.004	.009	.046

The effect of season on correlation between gages is apparent. All summer correlations are low, even though gages B and C are only 2.6 miles apart. Topography and storm patterns appear to be important factors in determining summer precipitation at a given point.

Temperature

Monthly mean temperature from a representative station in each vegetation type over a 23-year period is shown in figure 8. As expected, highest mean temperatures occur in July, with August slightly warmer than June. The coldest month is January; December is slightly colder than February except in the pine type.

Temperature differences among vegetation types may be explained in terms of elevation. A comparison of long term averages of annual mean temperatures at 46 stations throughout Arizona (National Climatic Center 1980) illustrates the elevation effect. A parabolic curve fits the data. A regression of annual mean temperature on elevation (fig. 9) yielded:

$$\hat{T} = 73.08 - 1.954E - 0.2494E^2$$

where $\hat{T}$ is annual mean temperature (°F) and E is elevation in thousands of feet. The regression had an r^2 value of 0.9406. The three Beaver Creek stations were all uniformly less than 1° F below the regression value. Stations used in the regression ranged in elevation from 191 to 7,320 feet.

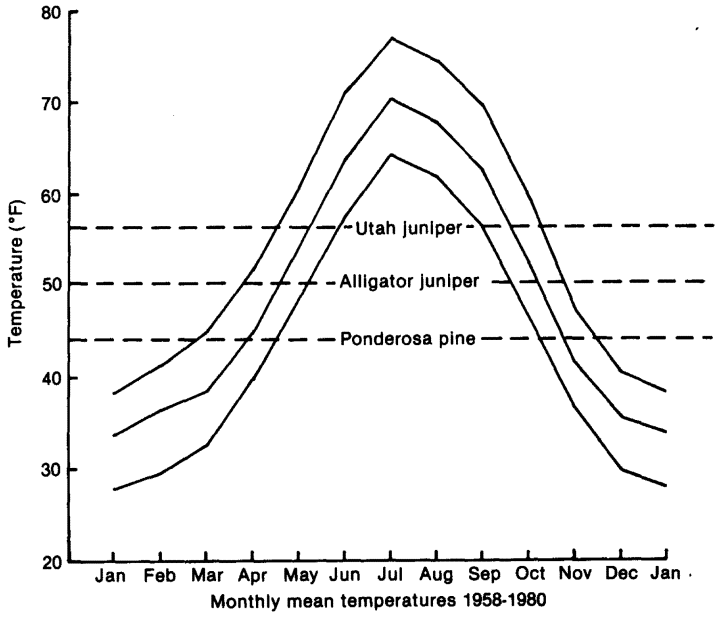

Figure 8.—Monthly mean temperatures of three stations representing three vegetation types on the Beaver Creek watersheds. Values are means of daily record from 1958 through 1980. Horizontal dashed lines are means of monthly values.

Mean monthly diurnal temperature fluctuations were greatest in June for all three types and least in December, February, or March. Diurnal fluctuations are greater every month in the pine type than in the juniper types. Extreme mean monthly diurnal fluctuations in the pine type are 38.3° F in June and 27.4° F in March; in the alligator juniper type they are 33.7° F in June and 23.4° F in January; in the Utah juniper they are 30.7° F in June and 25.4° F in December. For the year, the monthly mean diurnal fluctuations average 27.4° F in both the Utah and alligator juniper, and 31.0° F in the ponderosa pine type. Beschta (1976) also found greatest diurnal fluctuations in summer, and increasing diurnal fluctuation with increased elevation.

Relative Humidity

Average humidity (1972-1975) is highest in pine, intermediate in alligator juniper, and lowest in Utah juniper (table 11). This relationship is consistent with the precipitation and temperature differences among the three types. Humidity values for alligator juniper are not consistently higher than for Utah juniper. Mean maximum humidity is higher in most months in the alligator juniper, but mean minimum humidity is slightly higher in the Utah juniper.

The monthly and seasonal trends in relative humidity are similar to those found for the precipitation data. On all three vegetation types, June has the lowest mean

Table 11.—Mean monthly maximum and minimum relative humidity (percent) for stations in Utah juniper and alligator juniper woodlands, and in ponderosa pine forests (WY 1972 through 1975), Beaver Creek watersheds, Arizona

Month	Utah juniper				Alligator juniper				Pine			
	Mean max.	SD	Mean min.	SD	Mean max.	SD	Mean min.	SD	Mean max.	SD	Mean min.	SD
Jan.	86.0	15.1	38.0	15.2	82.0	10.1	35.8	13.4	95.0	4.7	49.3	14.3
Feb.	78.3	10.7	32.3	4.8	82.8	18.0	36.0	12.6	90.5	9.3	44.0	17.5
Mar.	86.5	14.9	40.0	15.0	85.5	25.6	39.5	15.9	92.3	7.0	48.0	20.8
Apr.	64.5	7.1	26.0	4.1	72.5	16.9	28.8	6.7	87.3	11.6	39.8	12.8
May	51.8	14.6	20.5	7.2	58.0	20.1	20.0	3.7	77.0	18.7	27.3	9.9
June	46.3	24.4	18.3	10.0	52.5	14.0	18.8	3.6	70.5	18.9	25.8	11.1
July	73.0	7.8	23.5	5.9	77.5	12.3	24.0	4.2	88.5	9.8	32.8	6.3
Aug.	63.3	16.3	23.0	10.2	70.3	6.6	21.5	3.0	92.8	4.8	33.0	9.0
Sept.	66.5	12.7	24.3	8.0	70.3	11.6	22.5	3.1	94.0	6.7	35.0	6.7
Oct.	66.5	18.3	31.8	20.3	73.0	12.4	26.8	9.8	92.3	6.0	43.0	17.3
Nov.	73.0	20.6	35.0	20.6	70.5	12.6	27.5	7.2	92.0	7.4	43.3	14.9
Dec.	80.5	9.1	31.0	13.3	80.0	10.6	28.0	5.2	96.8	1.5	43.5	8.2
Average	69.7		28.6		72.9		27.4		89.1		38.7	
SD	12.5		7.8		9.9		6.7		7.7		7.8	

maximum and minimum values while December-March have the highest mean maximum values. Similar trends in relative humidity have been reported by Beschta (1976) for ponderosa pine in central Arizona.

CONCLUSIONS

The data presented in this paper, collected on the Beaver Creek watersheds, are shown as a continuum of precipitation and temperature regimes in Arizona and New Mexico. Values are similar to those reported by Beschta (1976); thus they are applicable to the continuous ponderosa pine forests of the Coconino and Mogollon Plateaus in Central Arizona, and are related to climatic regimes throughout Arizona and New Mexico. However, small, isolated ponderosa pine forests could have quite different precipitation and temperature regimes.

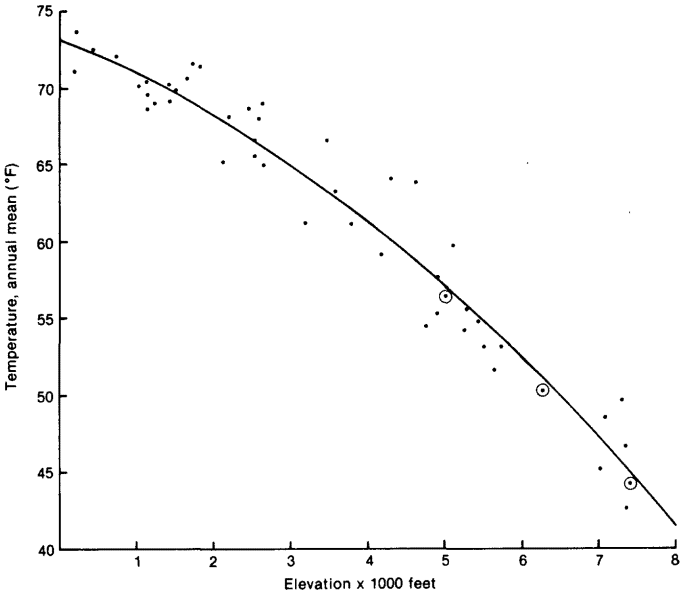

Figure 9.—Regression relation between annual mean temperature and elevation in Arizona. Data include all stations in Arizona with long-term records as reported in annual climatic summary (National Climatic Center, 1980). Beaver Creek stations are identified by ⊙.

Because western New Mexico and the Mogollon Rim country of Arizona not only contain similar vegetation (Lanner 1975, Schubert 1974, Tueller and Clark 1975) but are also influenced by the same weather patterns, the data can be used with some limitations by foresters in western New Mexico. In both areas, winter storms move east or northeast from the Pacific Ocean. Most of this precipitation falls in the mountains of central and southwestern Arizona and western New Mexico (Jameson 1969). Both areas receive summer precipitation from storms originating in the Gulf of Mexico (Sellers and Hill 1974), and receive very little precipitation in May and June. The climatic regime of eastern New Mexico is similar to that of the Great Plains, where most of the annual precipitation falls in the spring and summer (Jameson 1969, National Climatic Center 1980).

Southwestern Colorado and southern Utah have precipitation patterns similar to those of western New Mexico and north-central Arizona. The vegetation is similar also, and the climatic data presented here are related to the dry spring areas of these states.

With supplementation by local climatic records the information presented here can be used by managers for road and culvert planning and to help predict sediment yields from various management activities. In addition, long-term climatic records are often used as input for models that predict yields of herbage, timber, and water under alternative management prescriptions.

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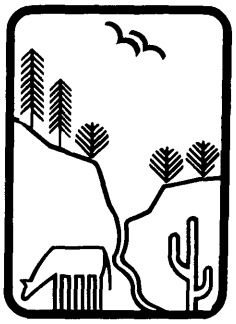
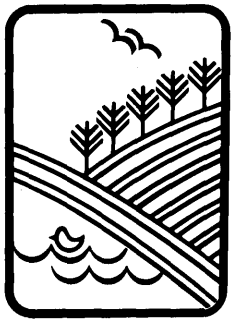
Rocky Mountains



Southwest



Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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